Topic 5: Stoichiometry - Chemical Arithmetic

Masses of some atoms:

$^{1}_{1}H = 1.6736 \times 10^{-24}\,g$ $\quad ^{16}_{8}O = 2.6788 \times 10^{-23}\,g$

$^{238}_{92}U = 3.9851 \times 10^{-22}\,g$

Introducing…….the Atomic Mass Unit (amu)

1 amu = 1.66054 x 10^{-24} g

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5.1: Atomic Mass Unit

Atomic Mass is defined relative to Carbon -12 isotope

12 amu is the mass of the $^{12}_{6}C$ isotope of carbon

Carbon -12 atom	=	12.000 amu
Hydrogen -1 atom	=	1.008 amu
Oxygen -16 atom	=	15.995 amu
Chlorine -35 atom	=	34.969 amu

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5.1: Atomic Mass - Natural Abundance

We deal with the **naturally occurring mix of isotopes**, rather than pure isotopes

Carbon has three natural isotopes

Isotope	Mass (amu)	Abundance (%)
^{12}C	12.000	98.892
^{13}C	13.00335	1.108
^{14}C	14.00317	1 x 10^{-4}

Any shovelful of Carbon from living material will have a **Naturally Occurring Abundance** of 98.892% ^{12}C, 1.108% ^{13}C and 0.0001% ^{14}C

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5.1: Atomic Mass - Relative Abundance

How do we take into account the naturally occurring Abundances?

Take the average mass of the various isotopes weighted according to their Relative Abundances

Isotope	Mass (amu)	Abundance (%)	Relative Abundance
^{12}C	12.000	98.892	0.98892
^{13}C	13.00335	1.108	0.0108
^{14}C	14.00317	1×10^{-4}	1×10^{-6}

N.B. The **% Abundance** adds up to **100**
The **Relative Abundance** adds up to **1**

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5.1: Average Atomic Mass

Isotope	Mass (amu)	Abundance (%)	Relative Abundance
^{12}C	12.000	98.892	0.98892
^{13}C	13.00335	1.108	0.0108
^{14}C	14.00317	1×10^{-4}	1×10^{-6}

The **Average Atomic Mass** is given by:

$$(0.98892 \times 12.000\ \textbf{amu}) + (0.01108 \times 13.00335\ \textbf{amu}) + (1 \times 10^{-6} \times 14.00317\ \textbf{amu}) = \underline{12.011\ \textbf{amu}}$$

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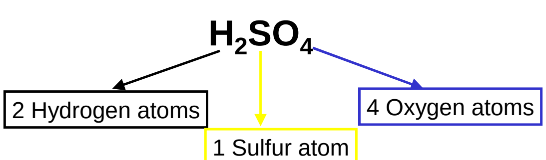
5.1: Atomic and Molecular Mass

You can calculate the mass of *any* compound from the *sum* of the atomic masses from the periodic table.

Example: **Molecular Mass of H_2SO_4**



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5.1: Molecular Mass

H_2SO_4

2 Hydrogen atoms

1 Sulfur atom

4 Oxygen atoms

(2 x 1.01 amu) + (1 x 32.07 amu) + (4 x 16.00 amu)

= 2.02 amu + 32.07 amu + 64.00 amu

= 98.09 amu

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5.1: Formula Mass

What is the formula mass of :

(Calcium nitrate tetrahydrate)

$Ca(NO_3)_2.4H_2O$?

1 Calcium

2 Nitrogens

8 Hydrogens

10 Oxygens

(1 x 40.08 amu) + (2 x 14.01 amu)
+ (8 x 1.01 amu) + (10 x 16.00 amu)
= 236.18 amu

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5.1: Formula Mass vs. Molecular Mass

Use MOLECULAR MASS when talking about MOLECULES

e.g. CO_2 H_2O $C_6H_{12}O_6$

Use FORMULA MASS when talking about IONIC COMPOUNDS

e.g. NaCl $Cu(NO_3)_2$ CaO

BUT the two terms are basically interchangeable

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5.2: How to Avoid Huge Numbers

Recall the introduction of Atomic Mass Units

1 amu = 1.66054×10^{-24} g

This avoids working with ridiculously small masses

How to avoid the problem of counting huge numbers of molecules / atoms ?

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5.2: How to Avoid Huge Numbers - Use moles!

How does a chemist say how many ATOMS or MOLECULES she reacted?

She talks of **moles** of Atoms or Molecules reacted

1 mole = 6.022142×10^{23}

Avogadro's Number (N_A)

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5.2: A mole is 6.02×10^{23} of anything

1 mole = 6.02×10^{23}

1 mole of PEANUTS, $KMnO_4$, ANTS, Br_2 molecules, BEERS, CH_3COOH = 6.02×10^{23} PEANUTS, $KMnO_4$, ANTS, Br_2 molecules, BEERS, CH_3COOH

The NUMBER is constant, NOT the MASS

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5.2: The mole: Where does it come from?

Definition:

1 mole is the number of Carbon atoms found in EXACTLY 12.00 g of ^{12}C

$12 \text{ amu} \times 6.02 \times 10^{23} = 12 \text{ g}$

$$12 \text{ amu} = \frac{12 \text{ g}}{6.02 \times 10^{23}}$$

$$12 \text{ amu} = \frac{12 \text{ g}}{1 \text{ mole}} = 12 \frac{\text{g}}{\text{mole}}$$

amu = g.mol^{-1}

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5.2: Molar mass

How to calculate the mass of 1 mole of a compound?

= the molecular mass in grams

H_2SO_4

2 Hydrogen atoms

1 Sulfur atom

4 Oxygen atoms

$$(2 \times 1.0079 \frac{\text{g}}{\text{mol}}) + (1 \times 32.065 \frac{\text{g}}{\text{mol}}) + (4 \times 15.999 \frac{\text{g}}{\text{mol}})$$

$$= 98.077 \text{ g . mol}^{-1}$$

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5.2: Molar mass

Examples:

1 molecule of KCl has molecular mass of 74.55 amu.,

1 mol of KCl has a mass of 74.55 g.,
and contains 6.02×10^{23} molecules of KCl.

1 mole of H_2O has a mass of **?** g

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5.2: Calculations of molar amounts

How many moles of ethanol (C_2H_5OH) are there in a schooner of beer?

(The average schooner contains 20.8 g ethanol)

Mass of ethanol = 20.8 g

Molar mass of ethanol = 46.08 g.mol^{-1}

$$\text{no. of moles of ethanol} = 20.8\ \text{g} \div 46.08\ \frac{\text{g}}{\text{mol}}$$

$$= 20.8\ \text{g} \times \frac{1}{46.08}\ \frac{\text{mol}}{\text{g}}$$

$$= 0.451\ \text{mol}$$

no. of moles = mass (g) / molar mass (g.mol^{-1})

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5.2: Calculations of molar amounts

How many moles of caffeine ($C_8H_{10}N_4O_2$) are there in a tin of Red Bull?

(1 tin contains 80 mg of caffeine)

Mass of $C_8H_{10}N_4O_2$ = 80 mg = 0.08 g

Molar mass of $C_8H_{10}N_4O_2$ = 194.22 g.mol^{-1}

$$\text{no. of moles of caffeine} = 0.08\ \text{g} \div 194.22\ \frac{\text{g}}{\text{mol}}$$

$$= 0.08\ \text{g} \times \frac{1}{194.22}\ \frac{\text{mol}}{\text{g}}$$

$$= 4 \times 10^{-4}\ \text{mol caffeine}$$

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5.2: Calculations of molecular amounts

How many MOLECULES of ethanol (C_2H_5OH) are there in a schooner of beer?

(The average schooner contains 20.8 g ethanol)

Mass of ethanol = 20.8 g

Molar mass of ethanol = 46.08 g.mol^{-1} } = 0.451 mol

No. of molecules 1 mole = 6.02×10^{23} molecules.mol^{-1}

no. of molecules of ethanol

$$= 0.451\ \text{mol} \times 6.02 \times 10^{23}\ \frac{\text{molecules}}{\text{mol}}$$

$$= 2.72 \times 10^{23}\ \text{molecules of ethanol}$$

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5.2: Calculations of molecular amounts

How many MOLECULES of nicotine ($C_{10}H_{14}N_2$) are there in an average cigarette (1.2 mg)?

Mass of nicotine = 1.2 mg = 1.2 × 10^{-3} g

Molar mass of nicotine = 162.26 g.mol^{-1}

No. of molecules 1 mole = 6.02 × 10^{23} molecules.mol^{-1}

Step 1: Convert mass to moles using molar mass

no. of moles of nicotine

= 1.2 × 10^{-3} g / 162.26 g.mol^{-1}

= 7.4 × 10^{-6} moles of nicotine

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5.2: Calculations of molecular amounts

How many MOLECULES of nicotine ($C_{10}H_{14}N_2$) are there in an average cigarette (1.2 mg)?

Mass of nicotine = 1.2 mg = 1.2 × 10^{-3} g

Molar mass of nicotine = 162.26 g.mol^{-1}

} = 7.4 × 10^{-4} mol

No. of molecules 1 mole = 6.02 × 10^{23} molecules.mol^{-1}

Step 2: Convert moles to molecules using Avogadro's number

no. of molecules of nicotine

= 7.4 × 10^{-6} mol × 6.02 × 10^{23} molecules.mol^{-1}

= 4.4 × 10^{18} molecules of nicotine

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1 mole = 6.022142 x 10^{23} things

1 mole = 6.022142 x 10^{23}

AVOGADRO'S NUMBER (N_a)

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